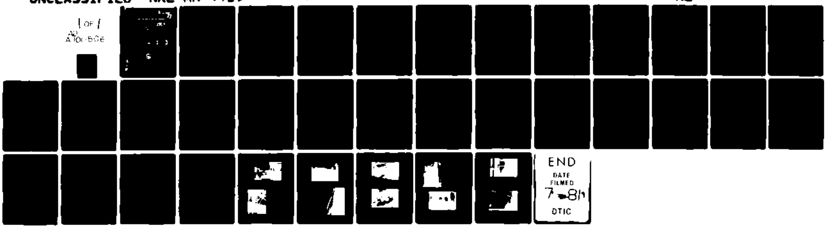
AD-A100 506 NAVAL RESEARCH LAB WASHINGTON DC F/G 13/11

SEA SALT SPRAY INGESTION BY FFG GAS TURBINES.(U)

JUN 81 R E RUSKIN, F K LEPPLE, R K JECK

UNCLASSIFIED NRL-MR-4419 NL



NAVAL RESEARCH LABORATORY
Washington, D.C.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Memorandum Report 4419	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) SEA SALT SPRAY INGESTION BY FFG GAS TURBINES		5. TYPE OF REPORT & PERIOD COVERED Final Report 4/11/-8/30/80
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) R. E. Ruskin*, F. K. Lepple & R. K. Jeck		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, DC 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 83-1270-0
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Sea Systems Command Washington, DC 20362		12. REPORT DATE June 9, 1981
		13. NUMBER OF PAGES 34
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) SEA 0399 Brian Rodda (PMS 399.12)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

*Present address: AMAF Industries, Inc.
103 Sterrett Building P.O. Box 1100 Columbia, MD 21044

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Sea salt spray measurements
Gas turbine air inlet filters
Gas turbine salt ingestion

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

At-sea measurements of salt spray in the FFG-13 main propulsion gas turbine intake found 50 times more salt than on the DD963 at similar sea state. This factor of 50 resulted from (a) ten times more salt being present upstream of the inlet filters because of the inlet placement lower and flush with the hull as compared to the DD963 inboard placement, and (b) at least five times greater percentage of salt penetration through the FFG knit mesh filter medium as compared to

(Continues)

DD FORM 1473 1 JAN 73 EDITION OF 1 NOV 65 IS OBSOLETE
S/N 0102-014-6601

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Continued)

the DD963 "barrier" or coalescer pad type of filter. The more "open" filter medium was needed on the FFG in order to minimize pressure drop across the filter with the smaller filter space which was available with allowance for the space required for a settling chamber or "drop space" upstream of the filters. This salt survey also determined that the drop space, while needed for green water, does not reduce the salt loading at the filter in the small particle sizes ($<20\ \mu m$) which create the principal problem in salt filtration.

(micrometers)

In view of this finding, NRL recommends (for the long term) retrofitting the filter mounting to change it from athwartship to diagonally fore-to-aft with a resultant reduction in drop space, but enlargement of the filter mounting space to permit use of the tighter (higher pressure drop) 963 type coalescer pads for combined inlet and secondary cooling air filtration. For the short term it is recommended that the previous monthly engine water wash cycle be supplemented with a daily non-detergent wash of the compressor stages during at-sea missions. The water tank plumbing may need to be upgraded in order to facilitate under-way washing.

Another finding of value for future ship inlet design is that outboard facing inlets which are flush with the hull receive 2.5 times more salt when on the lee side than on the windward side of the ship. This "lee vortex" effect could be minimized by either (a) installing a non-perforated catwalk outboard below the inlet louvers, (b) insetting the inlet by a distance about equal to its vertical dimensions, or (c) facing the inlets inboard or aft.

The salt survey findings on filter separation efficiency agreed closely with the NAPC Trenton wind tunnel measurements made with the same atmospheric salt particle sizes, although the NAPC data for these sizes (8-14 μm mass median diameter) were taken at 10 to 100 parts per million (PPM) instead of the actual atmospheric loading of 0.04 PPM found at the FFG inlet.

CONTENTS

SEA SALT SPRAY INGESTION BY FFG GAS TURBINES

INTRODUCTION

The objective of at-sea surveys of salt spray ingestion on Navy gas turbine ships is to increase time between overhaul and time to failure of gas turbine propulsion units on new and future types of Navy ships and to measure the operating characteristics of inlet salt aerosol separation systems on board the ships in the ambient sea atmosphere. This project is part of the turbine Inlet Placement Study to improve the design of present and future inlet and filter systems for improved protection of the turbine against failure from salt corrosion.

The FFG-7 class Guided Missile Frigate is restricted in the options for design of its inlet air filtration system because of the ship's low profile and limited deck space as compared to, for example, the DD963 SPRUANCE class. In order to compensate for the inlets being lower to the sea surface, hence more heavily loaded with salt spray, two design improvements over the DD963 inlet were incorporated, (a) hook vanes on the louvers, and (b) a "drop space" settling chamber to reduce the salt spray loading at the demister filters. A schematic of this arrangement is shown in Figure 1. However, the limited space available for filters precluded the use of "barrier" type demister pads having a high salt separation efficiency, such as those on the DD963 class because the pressure drop across the filters would have been excessive.

Wind tunnel tests by Naval Air Propulsion Center (NAPC), Trenton indicated that the "knit mesh" type filter medium as used on the FFG ships has several times more salt penetration than the barrier agglomerator pad plus "chevron" final stage as used on the DD963 class destroyers.

AT-SEA SALT SURVEY

Instrumentation was installed upstream and downstream of the demister filters as located in Figure 1. Additional salt sensors were located through the hull immediately below the inlet louvers and on the 02 deck above the inlets as indicated in Figure 2. Details of the instrumentation are presented in Appendix A.

Data from these instruments indicated that 50 times more PPM (parts per million) of salt in air were passing through the demister filters to the turbine intake than had been found at similar sea state conditions with similar instrumentation on an at-sea survey by the same research team on SPRUANCE. Averages from the composites of all of these instruments are summarized in Table I. Unfortunately, the FFG data were only available at low sea state. Therefore, they are compared in Table I with data on DD963 SPRUANCE at low sea state. At the bottom of Table I is shown the corresponding value of .001 PPM measured at high sea state on DD963. Using the same factor of 50 times more salt loading on FFG-13 than on DD963, NRL predicts a loading of .05 PPM to the FFG turbines at this higher sea state, exceeding the permissible load for the LM 2500 turbines.

Manuscript submitted March 6, 1981.

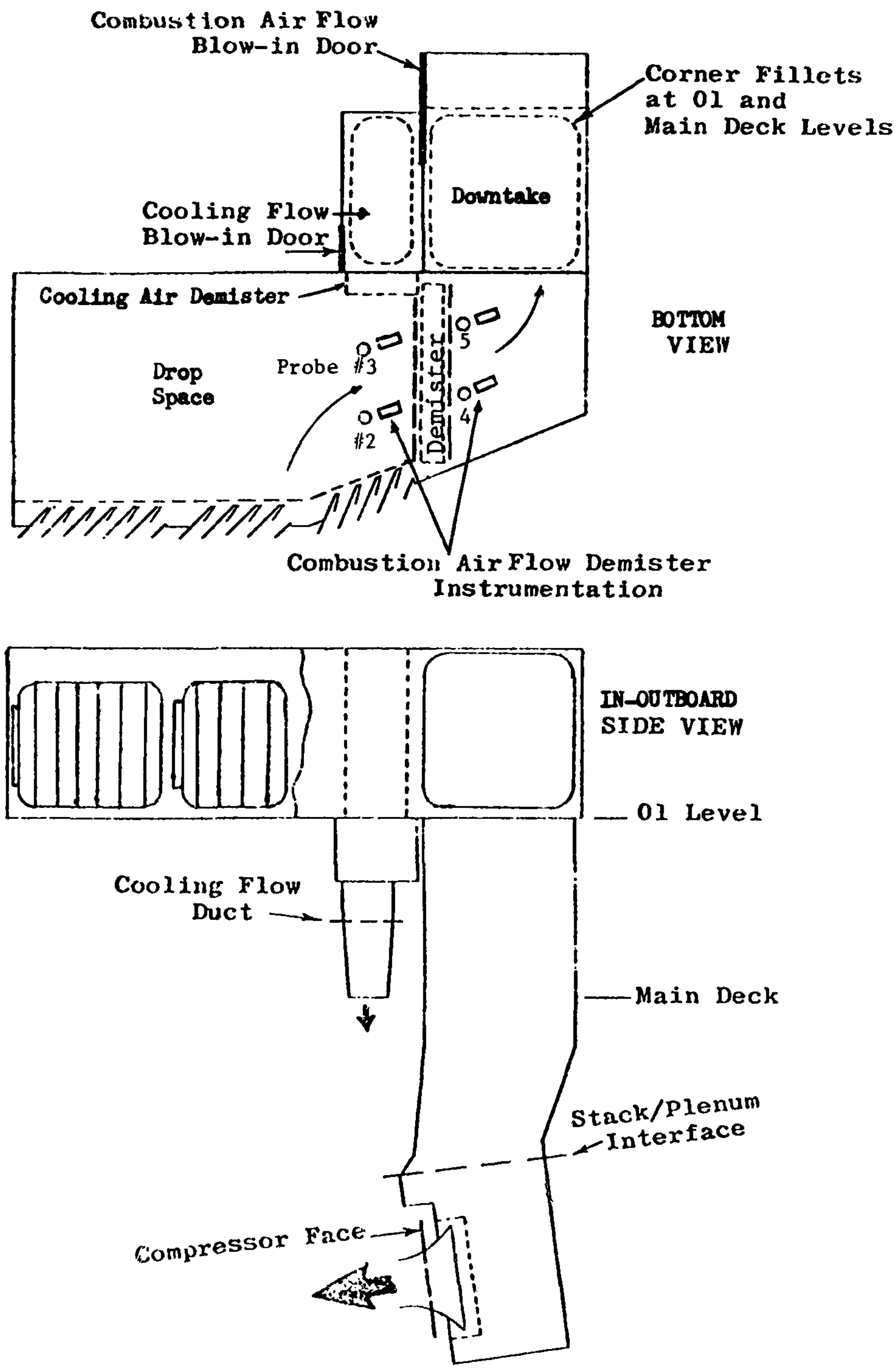


Fig. 1 — Schematic of FFG inlet

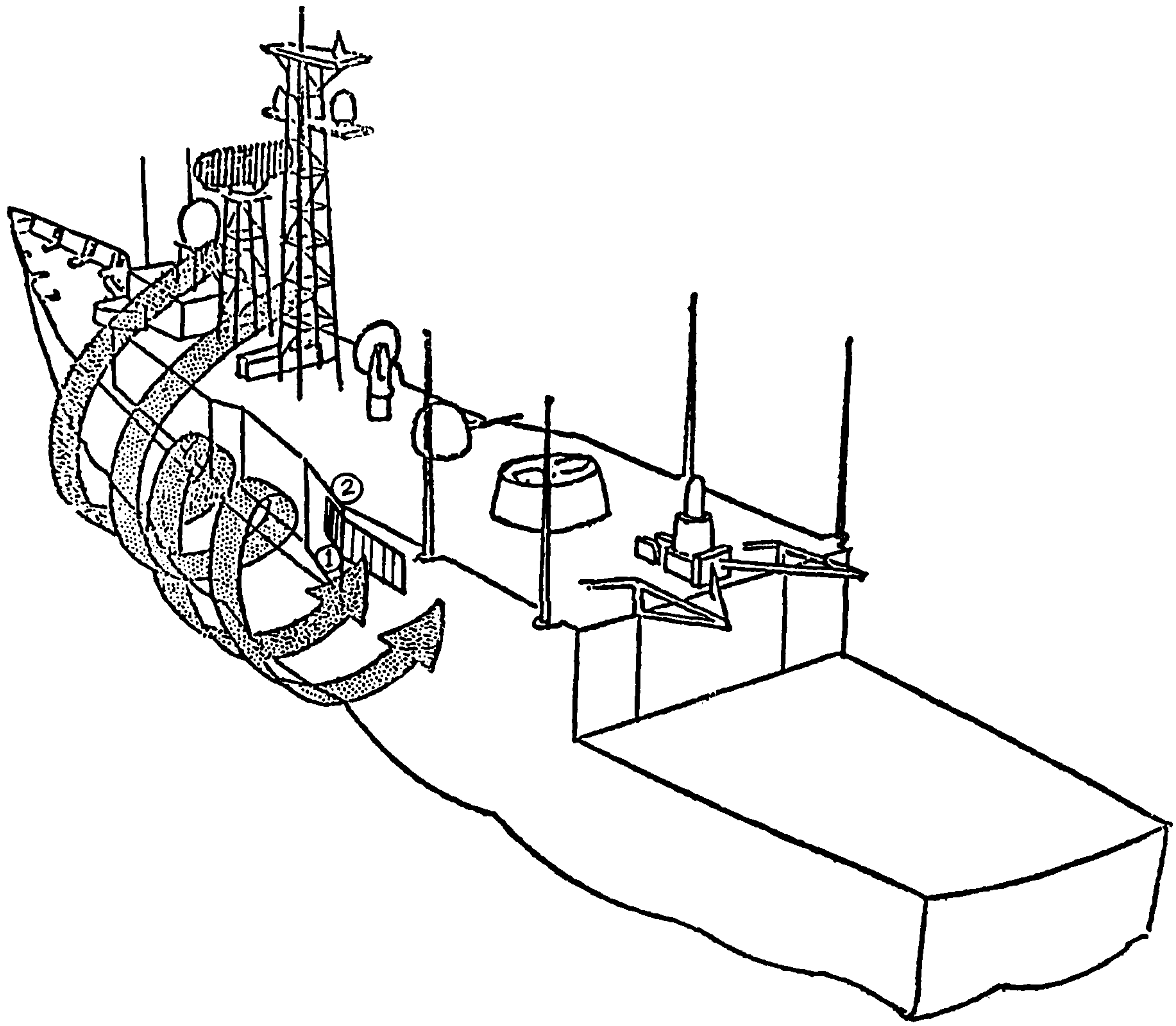


Fig. 2 — DTNSRDC wind tunnel model lee vortex. At-sea survey found 2.5X more salt loading on lee than upwind side. Instruments were mounted at 1 and 2 plus inside drop space and downstream of filters.

TABLE I

5-80 FFG-13 SALT SURVEY COMPARISON TO DD963

Low Sea State

	Upstream	Penetration Through Filter	Downstream
963	.004 PPM	<1%	<.00004 PPM
FFG	.04 PPM	>5%	>.002 PPM
Ratio $\frac{FFG}{963}$	10X	>5X	>50X

High Sea State

	Upstream	Penetration Through Filter	Downstream
963			.001
Expect FFG			>.05

DISCUSSION OF RESULTS

By comparing the salt loadings at several locations, an analysis can be made as to the factors contributing to this unacceptable level of salt to the turbines and what reduction in loading can be expected from different choices of possible changes in inlet design.

The effect of the filter medium can be seen by comparison of the upstream to downstream salt PPM. Table I shows a 1% penetration of salt spray through the 963 filter as compared to 5% on FFG. This factor of five times poorer separation efficiency combined with the factor of ten greater exposure loading results in the overall increase of 50X ratio of FFG to 963 salt ingestion to the turbines. At idle the filter penetration increased to 60%.

The effect of inlet placement is shown in the second column of Table I. The salt loading immediately upstream of the demisters was ten times higher on FFG-13 than on 963. This increase of 10X is less than NRL had expected because of the FFG low inlet location and placement of the inlet louvers flush with the hull as opposed to the 963 high inlets inset from the side of the hull. (It should be kept in mind that this factor of 10 could be worse at higher sea state.)

A further breakdown of the effects to be expected from some possible design changes can be seen in Table II. The second column presents averages of salt PPM loadings found at low sea state upstream of the filters on DD963 (.004 PPM) and FFG-13 (.04 PPM) compared to .07 PPM just below the inlet louvers. On the upper 02 deck just above the louvers the loading (.06 PPM) was 1.5 times that in the drop space adjacent to the filters. Judging by these values the average over the vertical extent of the louvers is approximately .065 PPM upstream of the louvers. The combined action of the louvers and drop space reduces the loading only by about 35% to .04 PPM at the filters. Whereas the louvers and some drop space are undoubtedly essential for protection from green water in high seas, they provided only minimal reduction of those salt particles which were generally smaller than 20μm (which constitutes the bulk of the spray that is difficult to remove by filters). The ineffectiveness of the drop space in reducing this salt loading was further verified by comparison of measurements near the outboard vs inboard sides of the drop space (with the probes separated by one-third of the drop space width). The inboard readings were consistently equal to or higher than the outboard values.

In Table II in the fifth line of numbers are tabulated the predicted salt loadings if the inlet air were brought into the drop space from the 02 deck. The last line indicates the further improvement which could be expected with the inlet raised above the 02 deck and faced inboard.

LEE VORTEX EFFECT

The amount of improvement by facing the inlet inboard vs outboard is derived by comparing the salt loading with the wind blowing toward the inlet (on the windward side) vs the loading when the inlet was on the lee side of the ship. These data were obtained by comparing salt to the engine during

TABLE II

SEA SALT LOADINGS (PPM) vs INLET DESIGNS

	Low Sea State			High Sea State	
	Upstream of filters	Downstream of knit mesh	Downstream w/barrier	Downstream w/knit mesh	Downstream w/barrier
DD963	.004		.00004		.001
FFG-13	.04	.002	(predicted) .0004	(predicted) .05	(predicted) .01
FFG Hull below louvers	.07 (10 foot vertical separation)				
Upper 02 deck	.056				
Predicted 02 deck + drop space	.025	.0013	.00025	.03	.006
Predicted 02 deck facing in	.016	.0005	.0001	.013	.0025

Conclusion: High sea state .05 PPM is a problem (50 X DD963). Predict fore-to-aft barrier 5X improvement (could live with). 02 deck face in: another 4X (probably not worth the major mod).

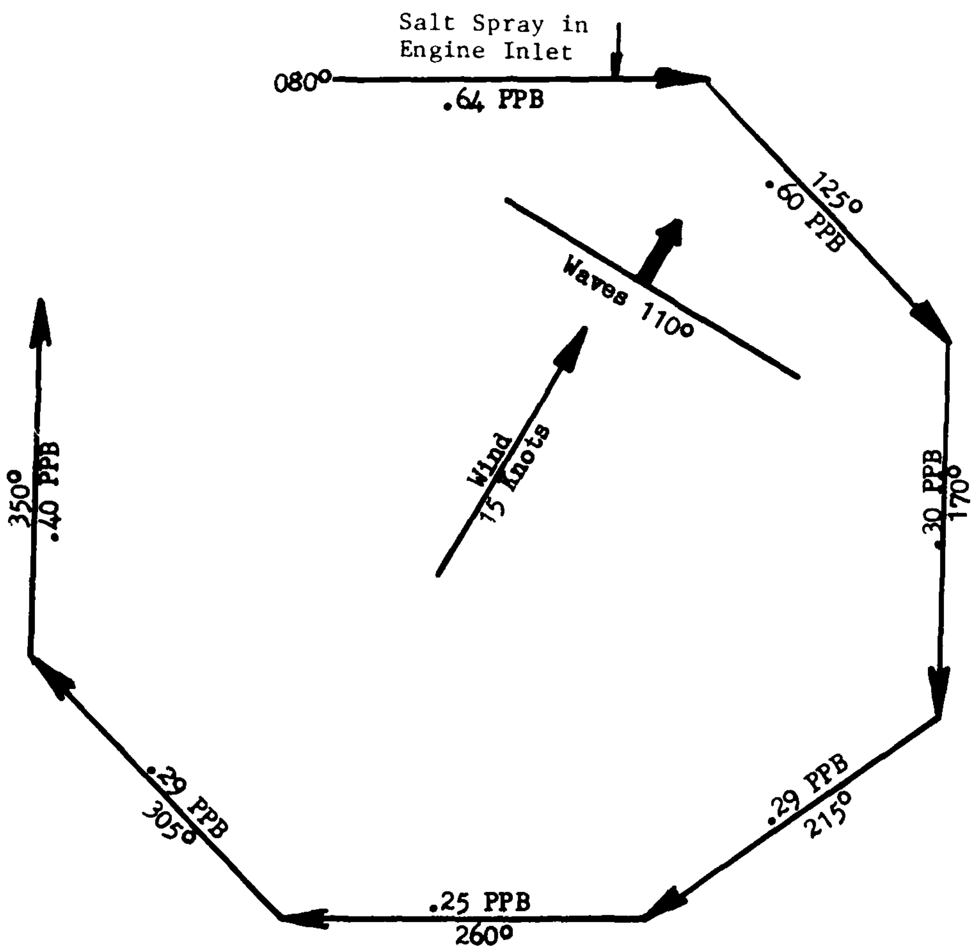


Fig. 3 — Parts per Billion (PPB) salt loadings during octagonal cruise pattern. Lee vortex (top of figure) gave higher salt loading than direct wind into inlet.

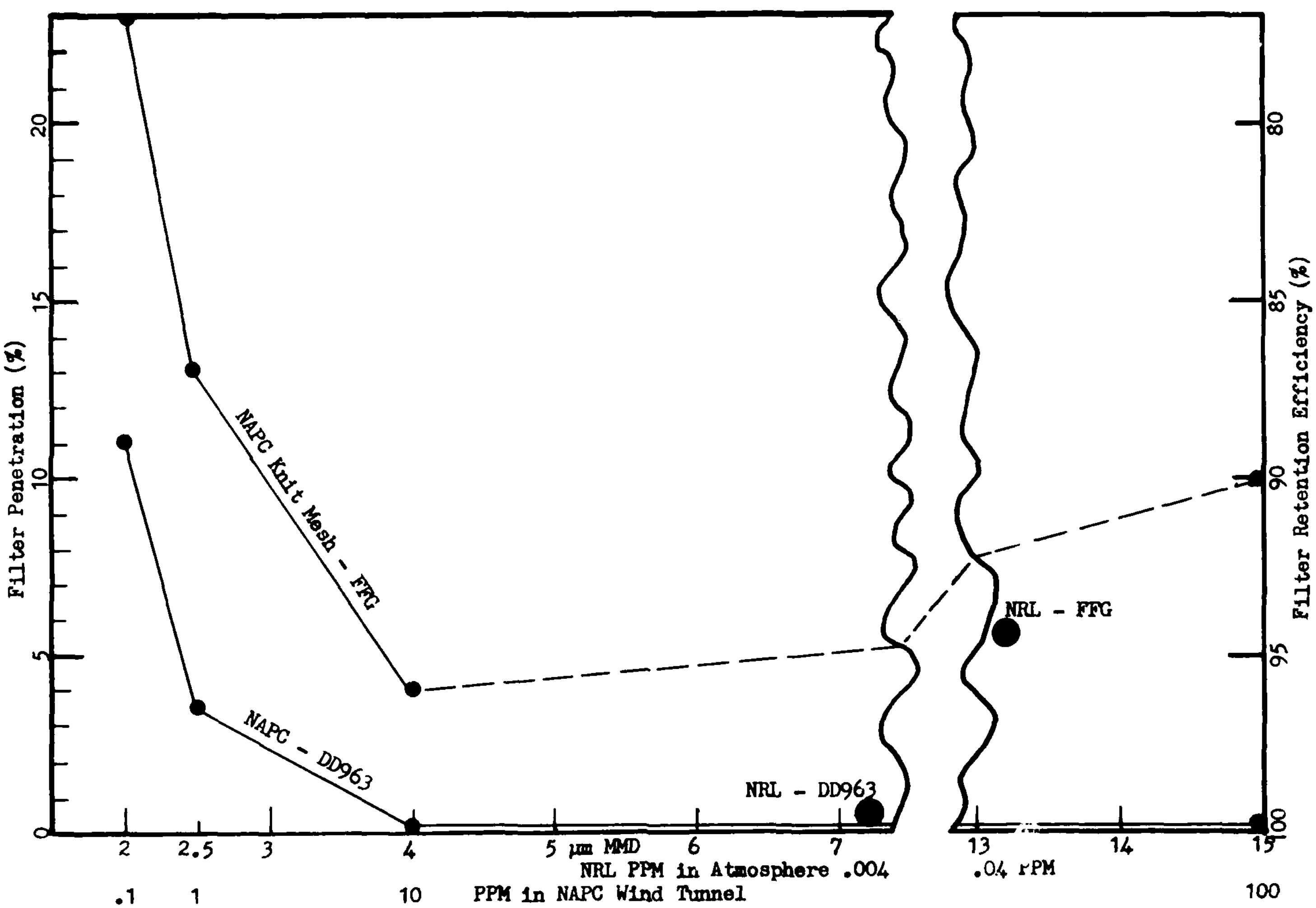


Fig. 4 — Filter penetration — FFG and DD963 per NAPC wind tunnel and NRL atmospheric data; lower scales: PPM salt loadings

each leg of an octagonal cruise pattern which was achieved by a series of 45^0 ship turns. These results are presented schematically in Figure 3. The loadings were 2.5 times higher when the inlet was on the lee side than when it was on the windward side. This result cooroborated previous findings on SPRUANCE and in wind tunnel tests at David Taylor Naval Ship Research and Development Center (DTNSRDC), Carderock, on a model of the FFG class ships. The DTNSRDC sketch of this lee vortex is shown in Figure 2. Salt is picked up from foam or spray at the sea surface and carried upward, wetting the lee side of the ship. This wetting effect could be minimized at the inlet by preventing the lee vortex from entering by (a) installing a non-perforated catwalk outboard below the inlet louvers, (b) insetting the inlet by a distance about equal to or greater than its vertical dimension, or (c) facing the inlets inboard or aft.

COMPARISON TO WIND TUNNEL FILTER DATA

The salt survey findings on filter separation efficiency agreed closely with the NAPC, Trenton wind tunnel measurements made with the same atmospheric salt particle sizes, although the NAPC data for these sizes (8-14μm mass median diameter) were taken at 10 to 100 parts per million (PPM) instead of the actual atmospheric loading of 0.04 PPM found at the FFG inlet.

Data from the wind tunnel tests are plotted in Figure 4 for both the knit mesh type of filter medium used on FFG and the barrier type agglomerator pad plus chevron stage as used on DD963. In Figure 4 the lefthand ordinate is labeled in terms of "filter penetration (%)" which is the same as 100% minus the filter separation efficiency as labeled on the righthand ordinate. Corresponding salt particle mass median diameters (MMD) are labeled along the abscissa. Below these MMD sizes are shown the PPM loadings at which these sizes occurred in the atmosphere at sea per NRL and a third scale showing the spray loadings which were used to produce the various MMD sizes in the NAPC wind tunnel.

From these curves it can be seen that the filter effectiveness is dependent mainly on the salt particle sizes (unless breakthrough occurs at very high loadings). Therefore, the NAPC data provide reliable values of filter efficiencies vs particle size if the PPM loadings are disregarded.

FFG CONCLUSIONS

1. FFG low inlets see 10X more salt than DD963 at low sea state.

2. FFG knit mesh has 5X the % penetration vs 963 barrier type.

3. Resultant salt loading to engine 50X 963 at low sea state.

4. Expect comparable increase at high sea states to give .05 PPM to engines (a problem).

5. Leaks around filter frames pass liquid water (may or may not increase PPM to engines beyond measured values).

6. Drop space essential for green water, but has little effect on 1-20 μ drops.

7. FFG smaller inlet filter space would give excessive ΔP with 963 barrier type.

8. Downwind lee vortex gave 2.5X higher salt loading than upwind inlet (a measure of expected improvement if inlets were facing inboard).

RECOMMENDATIONS

1. In view of the 50 times higher salt loading on FFG-13 than on DD963, the salt accumulated between monthly water washes on DD963 would be accumulated in a half day on FFG at the same sea state. Therefore, it is recommended that the FFG turbine monthly wash cycle with detergent be supplemented with a water wash after each mission on salt water and at least once per day during missions at any but the lowest sea states. It would probably be advisable to omit the detergent from these water washes since most of the salt is removed with water alone, and frequent removal by detergent of any oil film in the compressor could increase corrosion rates.

2. Valving and piping should be retrofitted if not presently available to permit expeditious water washing underway.

3. Inlet filter frames should be sealed to avoid the liquid water sometimes found on the deck downstream of the filters.

4. In the longer term, NRL recommends that future FFG ships be equipped with DD963 type barrier coalescer pads plus chevron stage in order to reduce the ingested salt to one-fifth of the previous loadings. Existing ships should be retrofitted.

5. With the space limitation of the present demister mount, the high velocity through the proposed barrier type filter would produce an unacceptably high pressure drop (ΔP). Therefore, it is recommended that the mount be redesigned to install diagonally fore-to-aft or, if necessary, extending straight longitudinally past the aft deck hatch in order to provide sufficient filter area for both main propulsion air and secondary cooling air with optimum ΔP and face velocity for best performance.

ACKNOWLEDGMENTS

Mr. Dennis Jung, Naval Sea Systems Command 523, initiated the FFG salt survey. Brian Rodda, PMS 399, sponsored the project. Messrs. Richard Weiss, Joseph Baron and Anthony DiGiovanni of the Naval Ships Systems Engineering Station, Philadelphia, assisted the NRL research team in all phases of the instrumentation and operation during the mission. Messrs. Walter Hicks and John Dennis of the Supervisor of Shipbuilding Office coordinated the ship modifications and survey execution. Mr. Larry Totten, Test Supervisor for Bath Iron Works, exercised great resourcefulness in mission planning and operations underway to provide the best opportunities for data acquisition. Mr. William Baker, BIW, provided coordination between NRL and BIW, and

Mr. David Hebblephwaite, Ship Superintendent, BIW, supervised and expedited ship modifications and on-board facilities for the survey. At NRL, Mr. Ron Beattie prepared the PMS instrumentation and assisted in its installation, and Mr. Walter Von Wald performed the engineering for the ship modifications and installation.

APPENDIX A

INSTRUMENTATION AND DATA TABLES

Three basically different types of instrumentation were used to evaluate the existing intake system on the FFG-13: Nuclepore membrane filter probes, optical aerosol measuring probes (Knollenberg and Royco) and a sodium aerosol spectrometer (Univ. of Washington design). The reason for the use of a variety of aerosol measuring instruments is that each type has different capabilities and limitations. The multiple instrument array also provides for comparisons and backup in case of malfunction. For example, the aerosol spectrometer measures the amount of sodium and the equivalent diameter of the dry salt "nucleus" but does not determine the size of the original moist particle or solution droplet that is seen by the demisters and by the optical aerosol measuring instruments. The Nuclepore filters provide data on total salt over a time interval but not the particle size data required for demister design improvements nor the short-term changes during specific ship maneuvers.

(1) Nuclepore Filter Probe Measurements

The NRL filter probe consists of a 5cm (2 inch) O.D. tube fitted with a filter screen holder and appropriate inlet cover which permits isokenetic aerosol sampling with a properly adjusted aspiration rate. Air is drawn through the filters in these probes by individually controlled vacuum pumps with flowmeters shown in Figure A-1. The aerosol sample is collected on a 25mm diameter Nuclepore filter having a pore size of 0.8μm diameter. Flow rates are typically 20-30 liters per minute. Material collected on the filters was analyzed at NRL by the method of x-ray fluorescence (XRF) to determine chloride content. Since sea water has a constant ratio of chloride ion to total salt, the analytical conversion to ppm of salt aerosol collected on the filters is straightforward and reliable. For this calculation, the total mass of air passing through the sample filter is determined from the flowmeter readings and the average density of the air during the sampling interval. The analytical precision of the XRF method at the 0 to 0.5 ppm salt level is better than ± 10%.

Four filter probes of 122cm length and one probe of 76cm length were deployed through the overhead in the helicopter repair shop (compartment 1-253-2-Q) as shown schematically in Figure 1 as circles numbered 2, 3, 4 and 5. The four long probes were mounted through the overhead using a ball valve/flange fitting (shown in Figure A-2) which enabled sampling downstream of the inlet louvers and ahead of and behind the FFG filters. The net penetration distance into this filter space varied from 48 to 53cm above the 01 deck level. A fifth probe (#1) was mounted through the port side bulkhead below the forward louver of the air inlet. The louvers (on the opposite side of the ship) are shown in Figure A-3. This probe extended approximately

58cm from the outer surface of the hull (8m above the waterline) with the filter opening facing forward. Figure A-4 is a view of this probe from above. The inlet openings of the other four filter probes were aligned with the mean flow pattern in the drop space and filter compartments. Probes designated #'s 2 and 3 were located in the drop space upstream of the knit mesh demisters while #'s 4 and 5 were located downstream of the demisters, 2 and 4 outboard, 3 and 5 inboard.

The sea salt aerosol concentration results are presented in Table A-1. After the dockside checkout run, the position occupied by filter probe #4 was occupied by one of the two Knollenberg optical measurement probes. In the cases where probes 2 and 3 were operated simultaneously, there are several instances where the values differed by as much as a factor of 10. It is reasonable to expect some nonuniformity upstream of the filters. Also, any relatively large droplets which enter the filter probe and are not truly representative of the aerosol in the entire drop space could bias the data to higher values. This points out the need for at least two simultaneous samples and some input from real-time sensors which can evaluate the statistical validity of samples taken over a small time increment.

Another sampler with its own self-contained pump was mounted topside on the 02 deck above the forward inlet louver. This sampler is visible at the port rail at the right of center in Figure A-5. The location dependence of ambient sea salt concentrations on FFG-13 is presented in Table A-2. The largest ratio of port hull (P) to topside (T) concentration values occurred while proceeding down the Kennebec River. Very little spray reached the 02 level deck. Similar topside values were found on the return trip up the river. The overall time-weighted average for the port hull salt aerosol concentration was 0.07 ppm compared to the value of 0.06 ppm for the topside sampler which is approximately 3m higher. This average ratio of 1.17 should be a minimum value since some of the port hull filters were visibly wet while those samples collected topside were always dry.

Table A-3 lists the calculated penetration values for the FFG-13 filter system. These values measure the effectiveness of the knit mesh in blocking salt particles once inside the drop space. As can be seen from Table A-1, the hook-vane louver effectiveness ranges from ~0% (tests 3,4,7,8,9 and 10) to 87% or 13% penetration in test #2. In Table A-3 the high penetration values for tests 1, 2 and 14 are probably due to smaller particle continental aerosols present during the dockside tests (#1) and river transit (#2 and 14). Tests 9 and 10 occurred during 30 knot operations and the wet probes and filters observed during those runs indicate that the knit mesh may have been partially saturated with the result that salt or particle droplet breakthrough occurred. Disregarding the dockside test and the river runs, the time-weighted average salt penetration for the mission was 6%.

(2) Particle Measuring System (PMS) Axially Scattering Spectrometer Probes (ASSP)

Electrooptical probes (sometimes called Knollenberg probes) are shown in Figures A-6 and A-7 and through the deck of the drop space near the center of Figure A-8. These probes measure the light forward-scattered from an

axial laser beam as each particle of salt spray or sand passes through the beam. The sizes of the electrical pulses generated by the light pulses are a function of the individual particle sizes. The pulses are sorted into 15 different size bins. These bins represent sizes of 0.3μm to 7μmm when the instrument is operating in one range. Every few seconds the range is automatically switched to a second range where the 15 bins represent sizes of 1 to 50μm. The 15 channels of pulses are accumulated usually for 10 seconds, then recorded on a digital tape cassette in a Hewlett-Packard 9825A computer mounted in the port helicopter hangar. (See right center of Figure A-9.) This computer is programmed to correct the droplet salinity for humidity and printout tables of particle PPM and mass median diameter (MMD) as presented in Tables A-4 through A-10.

In these tables the environmental and ship data are presented in the headings, and the percent of salt penetrating through the filters is tabulated at the end of each data set. The second column labeled "Ranges" indicates which of the instrument's four size ranges were used and programmed into the computer. The next column "WSPD(M/S)" indicates the airspeed through the probe as measured by a miniature hot wire type of air flowmeter installed inside the probe for calculation of PPM of salt/air. The "PPM" column is computed from the integration of 30 particle sizes, each corrected to dry size based on the amount of water in each droplet whose wet diameter was measured by the probe optics. The "Dry MMD" column tabulates the mass median diameter of these calculated dry sizes. "Wet MMD" indicates the mass median diameter which influences the filter efficiency. The last column "Swell" lists the factor used to convert the wet droplet sizes to dry salt content dependent on the relative humidity, which in turn is computed from the outside temperature and dewpoint.

(3) Royco Instruments Company Electrooptical Particle Counter

Two Royco counters were employed for the FFG-13 salt survey in order to supplement the PMS instruments for intercomparisons of salt upstream/downstream (for filter efficiency), inboard/outboard (for drop space effectiveness), and time changes for ship maneuver effects. The data presented in Figure 3 on the lee vortex effect is from these instruments. For time change data, two Royco's are needed in order to maintain a cross-check on instrument drift. Because of this tendency to drift, all intercomparison measurements require interchanging the two instruments at least once for each set of measurements.

The Royco design is less sophisticated than that of the PMS, resulting in more limitations on its use. Five size channels are available as compared to 15 in each of four ranges in the PMS. The optical sensor is a closed type which requires the sample to be transported into it, as opposed to the open type PMS probes which can be exposed directly in the air stream being measured. The sample is picked up by nearly isokenetic sampling heads which extend up from the sensor through the overhead and into the drop space upstream and inlet plenum downstream of the filters as shown in Figure A-10. The sampling head consists of an elbow designed to turn the sample flow from horizontal to vertically downward with a minimum of salt loss. The radius

of curvature of this elbow is calculated to avoid salt loss to the walls by balancing the centrifugal force in the turn and the gravity settling force to help maintain the particles in the airflow streamlines. Immediately below the elbow a porous stainless steel wall admits sheath air which reduces the tendency for particle loss to the walls of the tubing carrying the sample downward to the sensor. In practice the flow rates to the sensor must be measured and adjusted about once per hour in order to avoid sizeable errors in calculating the ppm of salt/air. The Royco electronics are shown in the center console in Figure A-9 and the data printout tapes are shown hanging down to the deck in the center and left consoles.

(4) University of Washington Sodium Aerosol Spectrometer (UWSAS)

The UWSAS burns the salt particles in a hydrogen flame and computes the salt content from the size of each light flash. This measurement avoids the uncertainty of the electrooptical instruments' conversion from their measured wet droplet sizes to find the dry salt sizes from an assumed humidity correction. The controls and self-contained computer are shown in the left console in Figure A-9. The hydrogen fuel tank is in the left corner. A hydrogen detector alarm is on top of the right console. Two detectors are located respectively in the top of the left console and in a hood over the sensor-burner located in the helicopter repair shop under the inlet filter. The samples are obtained from the same sampling heads used for the Royco counters discussed in section (3) above. On this cruise the UWSAS sampling pump malfunctioned such that it could not provide sufficient sample against the suction head in the inlet plenum. Therefore no satisfactory data were obtained. Fortunately sufficient redundancy had been designed into the total instrument system so that no vital data were missed.

(5) Ancillary Instrumentation

In order to convert the optical droplet sizes to dry salt content the relative humidity was automatically computed and incorporated into the computer program. For this computation the outside temperature and dewpoint were measured from a sensor on the 02 deck as shown mounted to the rail at the left side of Figure A-5. The data are cabled down to multiplexing circuits in the top and bottom of the right console in Figure A-9. The dewpoint instrument electronics are at the bottom of the center console. The data were recorded digitally on tape cassettes in the computer keyboard unit at the upper center of the right console and graphically on the recorder below the keyboard for monitoring and for hand calculations enroute.

Pressure in the intake plenum was monitored by an electrical transducer which was recorded on the analog (graphical) recorder and by a helicopter airspeed meter visible at the top of the left console in Figure A-9. Beside this airspeed (ΔP) meter are seen several flowmeters for sheath air and sample dilution air. This air is supplied from a pump, filter, and surge tank at the bottom of the left console.

Other shipboard installation efforts which are not visible in the figures included:

(a) The triple console of Figure A-9 was shock mounted to a foundation welded to the deck and to other shock mounts on sway braces to the bulkhead.

(b) A large number of cables and tubings were installed through the bulkhead into the helicopter shop behind the consoles.

(c) The deck of the 01 drop space and inlet plenum was provided with cut-outs for mounting flanges and welded sampler mounting pipe stubs visible at the bottom of Figure A-8 and at the top of A-2.

These and other ship modifications were provided through the cooperation of Bath Iron Works with the coordination of the Navy Supervisor of Shipbuilding in Bath, Maine.

Data furnished by cruise personnel included:

(a) True and relative wind speed and direction.

(b) Ship speed and heading.

(c) Propulsion gas turbine RPM.

(d) Sea state and wave directions.

A direct telephone line to the bridge expedited this data transfer.

TABLE A-1

Nuclepore Filter Data on Sea Salt Aerosol Concentration

			PPM Salt Aerosol*						
				Upstream		Downstream			
Date	Approx. Time	Test No.	Port Hull	Probe 2	Probe 3	Probe 4	Probe 5	Topside	
1980									
5/8	0940-1330	1	--	0.0012	--	0.0009	--	--	dockside BIW
5/12	1100-1200	2	0.1063	0.0023	0.0243	--	0.0021	0.0089	going downriver
5/12	1200-1330	3	0.0987+	0.0805+	0.1092	--	0.0013	0.1318	10-24 kts**
5/12	1330-1520	4	0.0111	0.0038	0.0337	--	0.0009	0.0021	10 kts**
5/12	1520-1620	5	0.0354+	0.0222	0.0220	--	0.0003	0.0034	10-20 kts**
5/12	1620-1730	6	0.1908+	0.0021	0.2112	--	0.0022	0.1172	20 kts**
5/12	1735-1900	7	0.0395+	0.0546+	--	--	0.0032	0.0738	0 kts**
5/12	1910-2115	8	0.0644+	0.0580+	0.0603+	--	0.0017	0.0716	0-31 kts**
5/12	2120-2300	9,10	0.0711+	0.1774+	0.0714+	--	{0.0441 0.0012	0.0247	30 kts**
5/12	2310-0000	11	0.0041	--	--	--	0.0015	--	25 kts**
5/13	0750-0850	12	--	0.0152	--	--	0.0003	--	Anchored
5/13	0900-1000	13	--	0.0322	--	--	0.0009	0.0046	proceeding
5/13	1010-1100	14	--	0.0013	--	--	0.0002	0.0053	upriver

*Plus sign after salt concentration values indicates wet filter samples with probability of salt aerosol losses

**Ship Speed

TABLE A-2

Location Dependence of Ambient Sea Salt Concentrations on FFG-13*

Test #	Time (approx)	PPM Salt Aerosol Port Hull (P)	PPM Salt Aerosol Topside (T)	Ratio (P/T)
2	1100-1200 (5/12)	0.106	0.009	118
3	1200-1330	0.099+	0.132	>0.8
4	1330-1520	0.011	0.002	5.5
5	1520-1620	0.035	0.003	11.7
6	1620-1730	0.191+	0.117	>1.6
7	1730-1900	0.040+	0.074	>0.5
8	1910-2115	0.064+	0.072	>0.9
9	2120-2300	0.071+	0.025+	>2.8
11	2310-0000	0.004	--	--
13	0900-1000(5/13)	--	0.005(Pond Is.)	--
14	1010-1100	--	0.005(Kennebec River)	--
	Time-weighted average =	0.07+	0.06	

*Measured by Nuclepore filter probes on the port side hull and on the 02 level deck above the port air intake louvers (approx. 0.6m from rail and 0.3m above deck level). Plus (+) values in table indicate wet filter samples with a high probability of sea spray aerosol loss to the walls of the filter holder.

TABLE A-3

Sea Salt Aerosol Penetration in FFG-13 Filters*

Test #	Filter Pair	Penetration
1	4/2	75%
2	5/2, 5/3	16%
3	5/2, 5/3	1.4%
4	5/2, 5/3	4.5%
5	5/2, 5/3	1.4%
6	5/2, 5/3	2.2%
7	5/2	5.8%
8	5/2	2.8%
9, 10	5/2, 5/3	19%
12	5/2	2.0%
13	5/2	2.8%
14	5/2	15%

*Comparison of salt concentration values from Nuclepore probes upstream (U) and downstream (D) of the knit mesh inlet filters expressed as penetration, $P=\left[1-\left(\frac{U-D}{U}\right)\right] \times 100\%$.

TABLE A-4

FFG-13 Salt Survey: PMS Probes

Date: 12 May 1980
Location: In Kennebec River
Ship Speed: 24 knots @ 260°
ΔP Across Filter: 2.4 inches H_2O
Port Turbine Gas Generator RPM: 8,400
Outside Temperature: 10.5C
Relative Humidity: 93%
True Wind: 15 knots @ 330°
Sea State: 1

NAPC ASSP Downstream

TIME	RANGES	WSPD(M/S)	PPM	DRY MMD	WET MMD	SWELL
1209:00	4,1	4.4	0.0026	1.05	3.69	3.5
1211:00	4,1	4.4	0.0001	0.29	1.03	3.5
1213:00	4,1	4.4	0.0001	0.20	0.69	3.5
1215:00	4,1	4.4	0.0001	0.20	0.69	3.5
1217:00	4,1	4.4	0.0001	0.20	0.69	3.5
1219:00	4,1	4.4	0.0001	0.23	0.80	3.5
1221:00	4,1	4.4	0.0001	0.20	0.69	3.5
1223:00	4,1	4.4	0.0001	0.20	0.69	3.5
1225:00	4,1	4.4	0.0001	0.20	0.69	3.5
1227:00	4,1	4.4	0.0002	0.20	0.69	3.5
		Avg.	0.00036		1.04	

NRL ASSP Upstream

TIME	RANGES	WSPD(M/S)	PPM	DRY MMD	WET MMD	SWELL
1209:00	4,1	7.4	0.0170	4.42	15.46	3.5
1211:00	4,1	7.4	0.0199	3.94	13.79	3.5
1213:00	4,1	7.4	0.0054	3.51	12.28	3.5
1215:00	4,1	7.4	0.0034	2.59	9.07	3.5
1217:00	4,1	7.4	0.0031	3.08	10.77	3.5
1219:00	4,1	7.4	0.0021	1.05	3.69	3.5
1221:00	4,1	7.4	0.0028	2.59	9.07	3.5
1223:00	4,1	7.4	0.0041	3.51	12.28	3.5
1225:00	4,1	7.4	0.0033	1.55	5.44	3.5
1227:00	4,1	7.4	0.0266	3.94	13.79	3.5
		Avg.	0.0088		10.6	

Filter Penetration - 4%

TABLE A-5

FFG-13 Salt Survey: PMS Probes

Date: 12 May 1980 — Location: At Sea
Ship Speed: 20 knots @ 259° — ΔP Across Filter: 2 inches H_2O
Port Turbine Gas Generator RPM: 5,800
Outside Temperature: 9.5C — Relative Humidity: 97%
True Wind: 20 knots @ 330° — Sea State: 1

NAPC ASSP Downstream

TIME	RANGES	WSPD(M/S)	PPM	DRY MMD	WET MMD	SWELL
1535:00	4,2	2.5	0.0013	0.35	1.21	3.5
1536:00	4,2	2.5	0.0001	0.19	0.65	3.5
1537:00	4,2	2.5	0.0002	0.19	0.65	3.5
1538:00	4,2	2.5	0.0002	0.19	0.65	3.5
1539:00	4,2	2.5	0.0002	0.19	0.65	3.5
1540:00	4,2	2.5	0.0002	0.19	0.65	3.5
1541:00	4,2	2.5	0.0002	0.19	0.65	3.5
1542:00	4,2	2.5	0.0002	0.20	0.69	3.5
1543:00	4,2	2.5	0.0002	0.20	0.69	3.5
1544:00	4,2	2.5	0.0002	0.19	0.65	3.5
1545:00	4,2	2.5	0.0002	0.19	0.65	3.5
		Avg.	0.0003		0.7	

NRL ASSP Upstream

TIME	RANGES	WSPD(M/S)	PPM	DRY MMD	WET MMD	SWELL
1535:00	4,2	5.5	0.0016	2.59	9.07	3.5
1536:00	4,2	5.5	0.0028	1.55	5.44	3.5
1537:00	4,2	5.5	0.0019	0.60	2.09	3.5
1538:00	4,2	5.5	0.0017	0.60	2.09	3.5
1539:00	4,2	5.5	0.0016	0.60	2.09	3.5
1540:00	4,2	5.5	0.0023	0.84	2.94	3.5
1541:00	4,2	5.5	0.0029	1.05	3.69	3.5
1542:00	4,2	5.5	0.0026	1.05	3.69	3.5
1543:00	4,2	5.5	0.0022	0.84	2.94	3.5
1544:00	4,2	5.5	0.0021	0.70	2.45	3.5
1545:00	4,2	5.5	0.0026	1.05	3.69	3.5
		Avg.	0.0022		3.65	

Filter Penetration - 14%

TABLE A-6

FFG-13 Salt Survey: PMS Probes

Date: 12 May 1980
Ship Speed: 20 knots @ 260° ΔP Across Filter: 3.3 inches H_2O
Port Turbine Gas Generator RPM: 6,800
Outside Temperature: 10C Relative Humidity: 97.4%
True Wind: 20 knots @ 330° Sea State: 1
Relative Wind: 27 knots @ 325°

NAPC ASSP Downstream

TIME	RANGES	WSPD(M/S)	PPM	DRY MMD	WET MMD	SWELL
1616:00	4,2	4.3	0.0008	1.04	3.65	3.5
1617:00	4,2	4.3	0.0001	0.35	1.22	3.5
1618:00	4,2	4.3	0.0001	0.35	1.22	3.5
1619:00	4,2	4.3	0.0001	0.33	1.14	3.5
		Avg.	0.0003		1.8	

NRL ASSP Upstream

TIME	RANGES	WSPD(M/S)	PPM	DRY MMD	WET MMD	SWELL
1616:00	4,2	7.3	0.0007	4.53	15.87	3.5
1617:00	4,2	7.3	0.0020	1.85	6.46	3.5
1618:00	4,2	7.3	0.0015	1.23	4.29	3.5
1619:00	4,2	7.3	0.0014	1.04	3.65	3.5
		Avg.	0.0014		7.6	

Filter Penetration - 20%

TABLE A-7

FFG-13 Salt Survey: PMS Probes

Date: 12 May 1980
Ship Speed: 24 knots @ 93°
ΔP Across Filter: 2.8 inches H_2O
Port Turbine Gas Generator RPM: 8,400
Outside Temperature: 9.5C
Relative Humidity: 95%
True Wind: 20 knots @ 330°
Sea State: 1
Relative Wind: 25 knots @ 45°

NAPC ASSP Upstream

TIME	RANGES	WSPD(M/S)	PPM	DRY MMD	WET MMD	SWELL
1945:30	4,2	7.0	0.0036	3.08	10.77	3.5
1946:30	4,2	7.0	0.0043	3.08	10.77	3.5
1947:30	4,2	7.0	0.0024	1.05	3.69	3.5
		Avg.	0.0034		8.4	

NRL ASSP Downstream

TIME	RANGES	WSPD(M/S)	PPM	DRY MMD	WET MMD	SWELL
1945:30	4,2	4.0	0.0008	0.60	2.09	3.5
1946:30	4,2	4.0	0.0002	0.19	0.65	3.5
1947:30	4,2	4.0	0.0002	0.19	0.65	3.5
		Avg.	0.0004		1.1	

Filter Penetration - 11.7%

TABLE A-8

FFG-13 Salt Survey: PMS Probes

Date: 12 May 1980
Ship Speed: 31 knots @ 72°
ΔP Across Filter: 3.5 inches H_2O
Port Turbine Gas Generator RPM: 8,400
Outside Temperature: 9.8C
Relative Humidity: 95%
True Wind: 18 knots @ 330°
Sea State: 1
Relative Wind: 20 knots @ 040°

NAPC ASSP Upstream

TIME	RANGES	WSPD(M/S)	PPM	DRY MMD	WET MMD	SWELL
2000:30	4,2	8.0	0.0045	2.59	9.07	3.5
2001:30	4,2	8.0	0.0088	3.51	12.28	3.5
2002:30	4,2	8.0	0.0042	2.59	9.07	3.5
2003:30	4,2	8.0	0.0131	5.43	19.01	3.5
2004:30	4,2	8.0	0.0099	3.94	13.79	3.5
2005:30	4,2	8.0	0.0050	3.08	10.77	3.5
2006:30	4,2	8.0	0.0118	3.94	13.79	3.5
2007:30	4,2	8.0	0.0062	2.02	7.06	3.5
2008:30	4,2	8.0	0.0066	2.59	9.07	3.5
2009:30	4,2	8.0	0.0105	3.94	13.79	3.5
		Avg.	0.0081		11.1	

NRL ASSP Downstream

TIME	RANGES	WSPD(M/S)	PPM	DRY MMD	WET MMD	SWELL
2000:30	4,2	5.0	0.0002	0.19	0.65	3.5
2001:30	4,2	5.0	0.0003	0.20	0.69	3.5
2002:30	4,2	5.0	0.0002	0.19	0.65	3.5
2003:30	4,2	5.0	0.0002	0.19	0.65	3.5
2004:30	4,2	5.0	0.0002	0.19	0.65	3.5
2005:30	4,2	5.0	0.0002	0.19	0.65	3.5
2006:30	4,2	5.0	0.0002	0.19	0.65	3.5
2007:30	4,2	5.0	0.0002	0.19	0.65	3.5
2008:30	4,2	5.0	0.0002	0.19	0.65	3.5
2009:30	4,2	5.0	0.0002	0.17	0.59	3.5
		Avg.	0.0002		0.65	

Filter Penetration - 2.6%

TABLE A-9

FFG-13 Salt Survey: PMS Probes

Date: 12 May 1980
Ship Speed: 30 knots @ 305°
ΔP Across Filters: 2 inches H_2O
Port Turbine Gas Generator RPM: 8,400
Outside Temperature: 9C
Relative Humidity: 98.7%
True Wind: 10 knots @ 130°
Sea State: 1
Relative Wind: 30 knots @ 320°

NAPC ASSP Upstream

TIME	RANGES	WSPD(M/S)	PPM	DRY MMD	WET MMD	SWELL
2141:30	4.2	7.6	0.0042	5.90	20.63	3.5
2142:30	4.2	7.6	0.0055	3.94	13.79	3.5
2143:30	4.2	7.6	0.0023	1.55	5.44	3.5
2144:30	4,2	7.6	0.0035	3.08	10.77	3.5
2145:30	4,2	7.6	0.0028	2.59	9.07	3.5
2146:30	4,2	7.6	0.0020	1.55	5.44	3.5
		Avg.	.00338		11.5	

NRL ASSP Downstream

TIME	RANGES	WSPD(M/S)	PPM	DRY MMD	WET MMD	SWELL
2141:30	4,2	4.6	0.0020	1.55	5.44	3.5
2142:30	4,2	4.6	0.0002	0.17	0.59	3.5
2143:30	4,2	4.6	0.0002	0.17	0.59	3.5
2144:30	4,2	4.6	0.0002	0.17	0.59	3.5
2145:30	4,2	4.6	0.0002	0.17	0.59	3.5
2146:30	4,2	4.6	0.0002	0.17	0.59	3.5
		Avg.	0.0005		1.4	

Filter Penetration - 14.8%

TABLE A-10

FFG-13 Salt Survey: PMS Probes

Date: 13 May 1980 Location: Approaching Boothbay
Ship Speed: 25 knots
Port Turbine Gas Generator RPM: 7,800
Sea State: 0

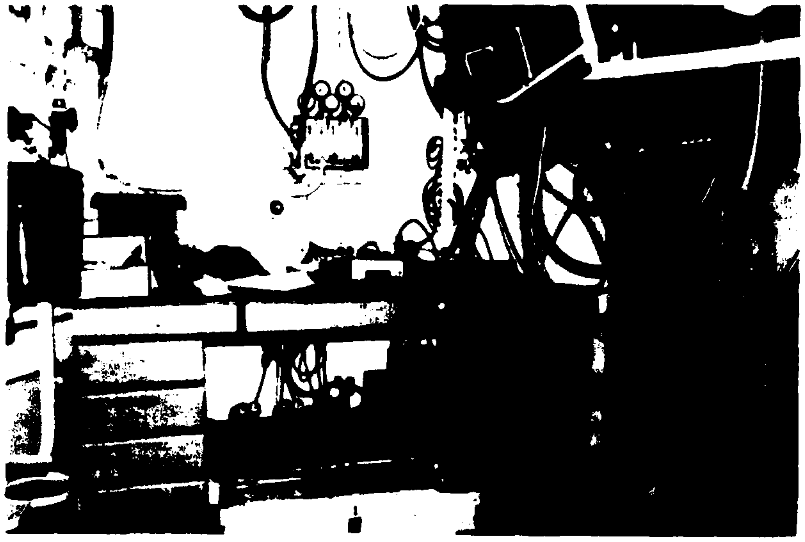
NAPC ASSP Outside Hull Below Louvers

TIME	RANGES	WSPD(M/S)	PPM	DRY MMD	WET MMD	SWELL
0005:30	4,2	11.3	0.0013	2.02	7.06	3.5
0006:30	4,2	11.3	0.0021	5.43	19.01	3.5
0007:30	4,2	11.3	0.0057	4.95	17.32	3.5
0008:30	4,2	11.3	0.0032	3.94	13.79	3.5
0009:30	4,2	11.3	0.0012	2.59	9.07	3.5
0010:30	4,2	11.3	0.0018	3.94	13.79	3.5
0011:30	4,2	11.3	0.0014	2.59	9.07	3.5
0012:30	4,2	11.3	0.0012	3.08	10.77	3.5
0013:30	4,2	11.3	0.0019	4.42	15.46	3.5
0014:30	4,2	11.3	0.0010	2.59	9.07	3.5
0015:30	4,2	11.3	0.0021	5.43	19.01	3.5
0016:30	4,2	11.3	0.0017	5.43	19.01	3.5
0017:30	4,2	11.3	0.0025	5.90	20.63	3.5
0018:30	4,2	11.3	0.0021	3.94	13.79	3.5
0019:30	4,2	11.3	0.0043	3.94	13.79	3.5
0020:30	4,2	11.3	0.0025	3.51	12.28	3.5
0021:30	4,2	11.3	0.0009	1.05	3.69	3.5
		Avg.	0.0022		13.33	

NRL ASSP Downstream of Filters

TIME	RANGES	WSPD(M/S)	PPM	DRY MMD	WET MMD	SWELL
0005:30	4,2	3.3	0.0002	0.17	0.59	3.5
0006:30	4,2	3.3	0.0002	0.17	0.59	3.5
0007:30	4,2	3.3	0.0002	0.17	0.59	3.5
0008:30	4,2	3.3	0.0002	0.17	0.59	3.5
0009:30	4,2	3.3	0.0002	0.17	0.59	3.5
0010:30	4,2	3.3	0.0002	0.17	0.59	3.5
0011:30	4,2	3.3	0.0003	0.19	0.65	3.5
0012:30	4,2	3.3	0.0002	0.17	0.59	3.5
0013:30	4,2	3.3	0.0002	0.17	0.59	3.5
0014:30	4,2	3.3	0.0002	0.17	0.59	3.5
0015:30	4,2	3.3	0.0002	0.17	0.59	3.5
0016:30	4,2	3.3	0.0002	0.17	0.59	3.5
0017:30	4,2	3.3	0.0002	0.17	0.59	3.5
0018:30	4,2	3.3	0.0002	0.17	0.59	3.5
0019:30	4,2	3.3	0.0002	0.17	0.59	3.5
0020:30	4,2	3.3	0.0002	0.17	0.59	3.5
0021:30	4,2	3.3	0.0002	0.17	0.59	3.5
		Avg.	0.0002		0.593	

Penetration through louvers, drop space, and filters: 9%

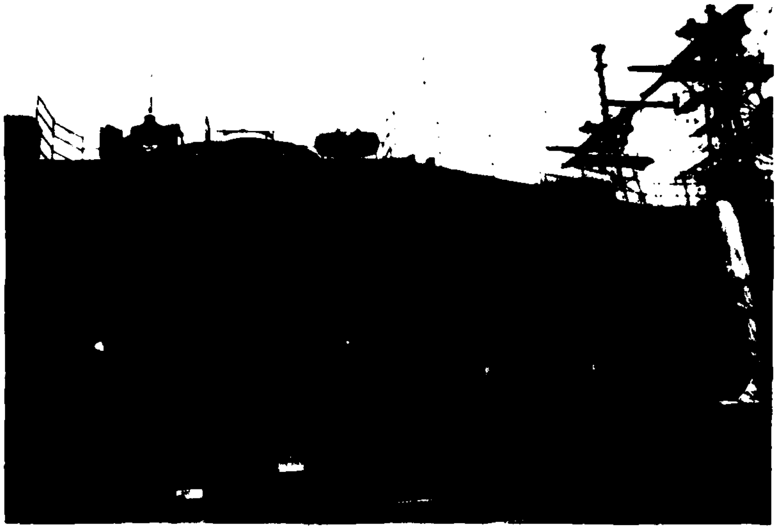


R-033

Fig. A-1 — Nuclepore air pumps under workbench in helicopter repair shop on main deck level; probe below on tool chest; nuclepore flowmeters with vacuum gauges on wall bracket, center; on workbench right of center, readout of portable flowmeter for Royco; upper right, UWSAS sensor hood and bracket

R-034

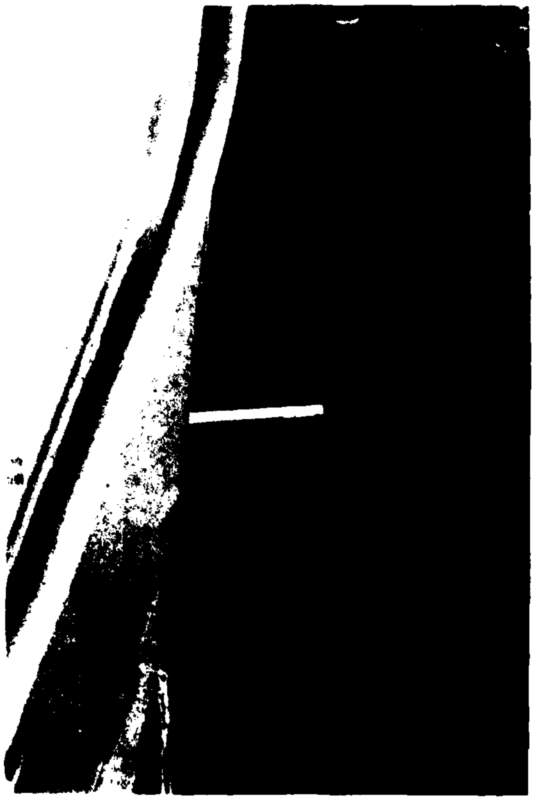
Fig. A-2 — Nuclepore probe installed through air lock; ball valve above screwed to pipe stub welded through overhead into drop space on 01 level



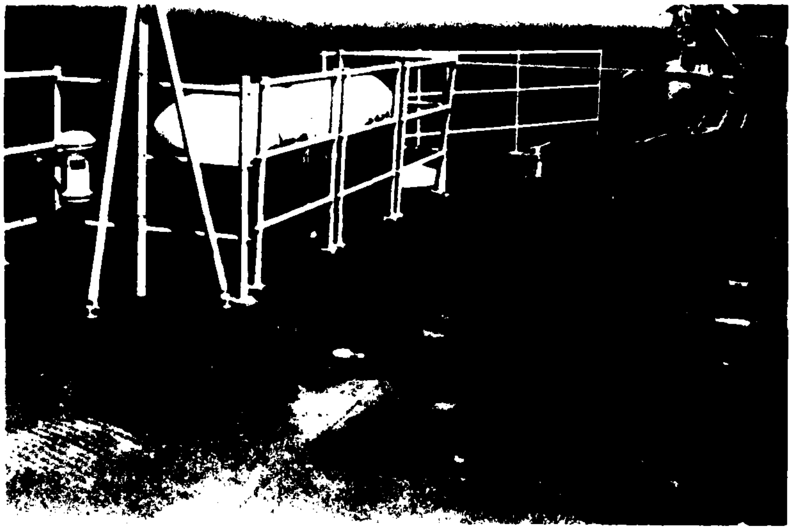
R-037

Fig. A-3 — FFG at dockside, showing inlet hooked louvers; instrumentation was installed on opposite side of ship near the louvers

Fig. A-4 — Nuclepore filter probe installed through side hull below inlet; louver is visible in foreground, lower left

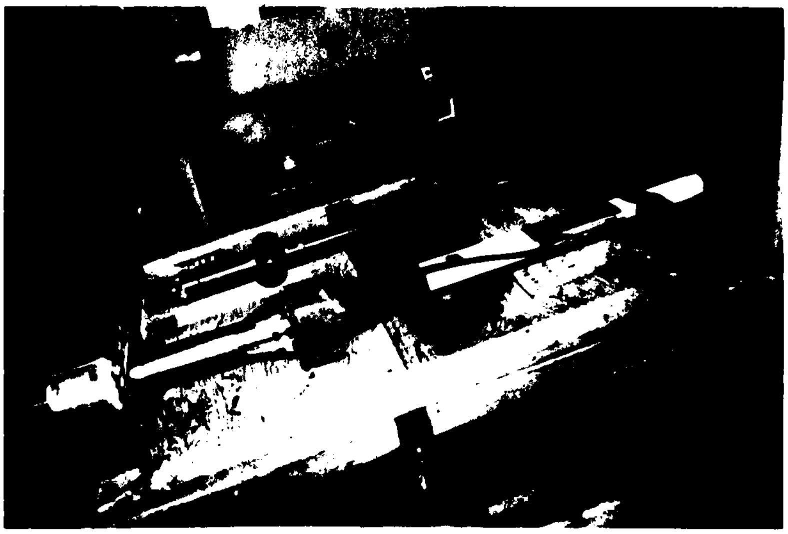


R-038



R-039

Fig. A-5 — Topside (02 level) deck with Nuclepore probe and pump mounted at port rail of right of center; dewpoint and temperature sensor housing is mounted on rail at left



R-040

Fig. A-6 — PMS ASSP probes; one in foreground is mounted to support pedestal and clamp through the deck mounting plate at left; cable to flowmeter is visible leading to sampling housing at right

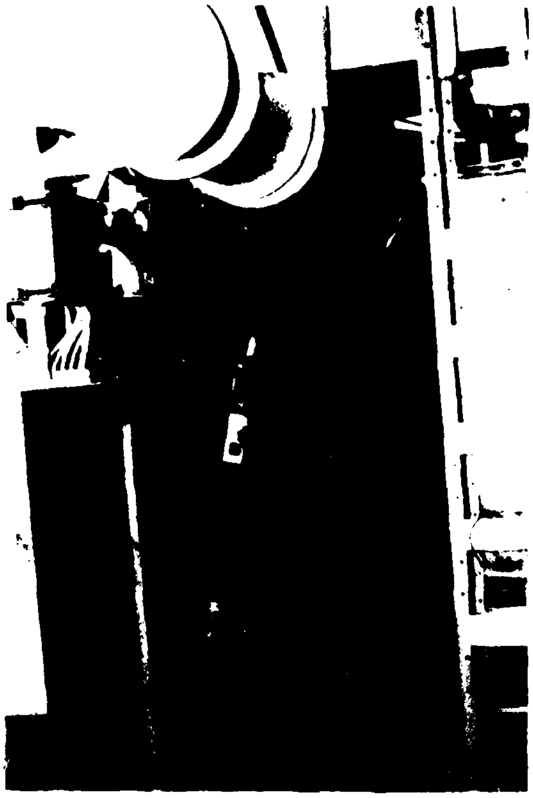
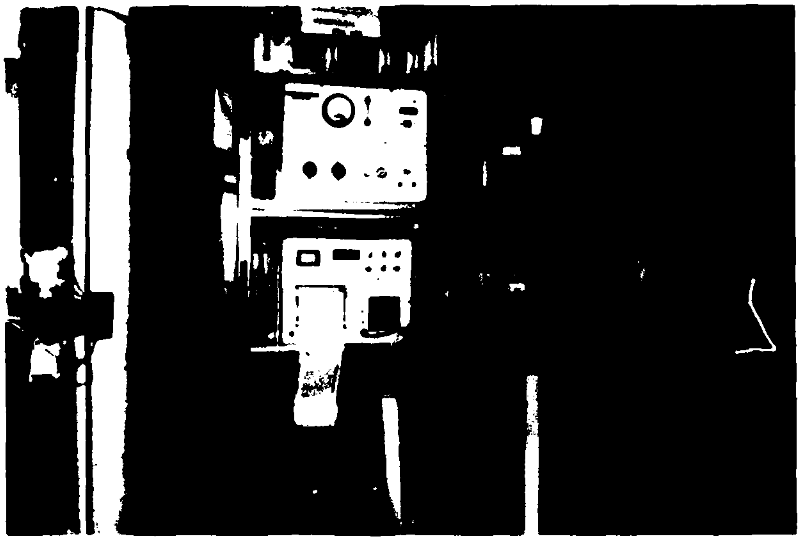


Fig. A-7 — PMS probe ready for installation through overhead in helicopter repair shop

R-041

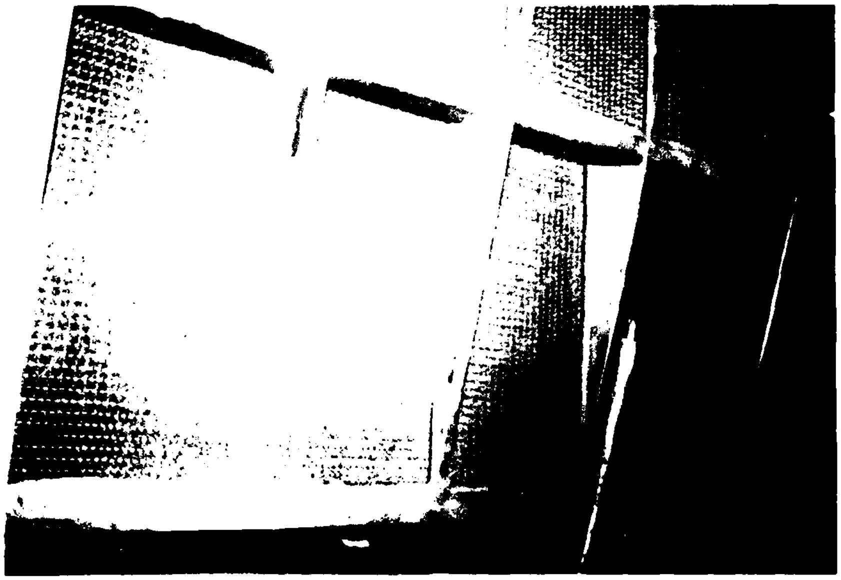
R-042

Fig. A-8 — Drop space upstream of inlet filters showing deicing manifold (at workman's hand), PMS probe through deck at center, two pipe stubs welded through deck for Nuclepore probes in foreground, inlet filter pad at right leaning against cooling air filter deicer; inlet louver is at left



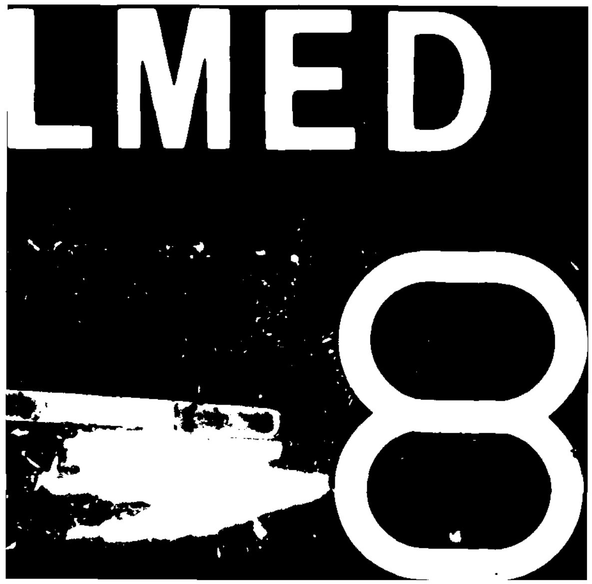
R-035

Fig. A-9 — Instrumentation control and electronics triple console in helicopter hangar. Right console top to bottom are hydrogen leak detector alarm, computer input/output switching unit, computer keyboard/calculator unit, analog (graphical) recorder, PMS data and control electronics, and computer multiplexer; center console two Royco electronics and control units, Royco data printer with data tape hanging down to deck, and dewpoint/temperature electronics and control unit; left console flowmeters and airspeed meter for pressure drop across inlet filter to inlet plenum, UWSAS control and pump unit, UWSAS data handling unit with computer and recorder, second Royco data printer, and dilution air pumps, filter and surge tank; in left corner behind console, hydrogen fuel tank for UWSAS.



R-036

Fig. A-10 — Downstream side of inlet filters in inlet plenum; Royco sampling head through deck; small static tube attached to sampling elbow at top provides static pressure air to ΔP sensors


LMED
8